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Preventing Hydrogen Explosions at Indian Point Nuclear Plant: Fact versus Industry Spin

Entergy and the Nuclear Regulatory Commission Make Inaccurate Statements Regarding the Indian Point Energy Center's Capacity to Prevent Hydrogen Explosions in the Event of a Severe Nuclear Accident

NRDC

THE EARTH'S BEST DEFENSE

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Entergy Has Not Adequately Equipped Indian Point to Minimize the Threat of a Hydrogen Explosion in the Event of a Core Meltdown

On November 14, 2012, the New York clean water advocacy group Riverkeeper filed a 10 C.F.R. § 2.206 enforcement action petition requesting that the Nuclear Regulatory Commission (NRC) permanently shut down Indian Point Units 2 and 3 because the current license holder has failed to adequately mitigate the risk that hydrogen produced in a severe accident could accumulate and explode with sufficient force to breach Indian Point's Unit 2 and 3 containment buildings, thereby exposing the public to a large radiological release.[1]

When a core meltdown occurs in a nuclear reactor, such as the triple melt-down that occurred during Japan's Fukushima nuclear accident in March 2011, the final barrier to protect the public from a radiological release is the reactor's containment.[2] The NRC does not require owners of pressurized water reactors with large dry containments to control the hydrogen that would be generated in a meltdown.[3] An NRC task force report on insights from the Fukushima Dai-ichi accident claims that the pressure spike of potential hydrogen explosions would remain within the design pressure of large dry containments.[4] According to the NRC's own safety analyses, however, conducted a decade ago, hydrogen explosions inside large dry containments could cause pressure spikes exceeding 110 pounds per square inch,[5] which is about twice the design pressure of Indian Point's containments.[6]

If a meltdown were to occur at either of Indian Point's two reactors, a large quantity of potentially explosive hydrogen would be produced when reactor core materials, principally the zirconium alloy tubes that contain the nuclear fuel, chemically reacted with steam. There is no assurance today that Indian Point's owner, Entergy, could control the total quantity of hydrogen generated in a meltdown—which could exceed 1,000 kilograms[7]—and prevent a hydrogen detonation that would breach the containment and spew radioactive contamination into the regional environment.[8]

Indian Point is located in Buchanan, New York on the Hudson River, 34 miles north of Central Park in New York City. According to a recent Natural Resources Defense Council (NRDC) report, if winds were blowing south, a release of radiation from Indian Point—on the scale of the Fukushima Dai-ichi accident—could contaminate a swath of land between Buchanan and the George Washington Bridge, rendering it uninhabitable for generations. An accident releasing radiation on the scale of the Chernobyl accident could render Manhattan uninhabitable.[9]

Despite the devastating occurrence of such hydrogen explosions at Fukushima, both Entergy and the NRC refuse to acknowledge this continuing vulnerability in Indian Point's defenses against a severe accident. Instead, Entergy and the NRC offer the public false assurances that the reactors are properly equipped to minimize this risk.

Indian Point Has a Very Limited Capacity for Controlling Hydrogen

On November 15, 2012, the *Poughkeepsie Journal* published an article, "Riverkeeper Petitions NRC to Shut Indian Point: Environmental Group Says Accident Could Cause Explosion."[10] This article states that Jerry Nappi, an Entergy spokesman, "disagreed with the petition's premise," and goes on to quote Mr. Nappi directly as follows: "Indian Point is designed with back-up safety equipment to protect the plant, including equipment inside containment that automatically turns hydrogen gas into harmless water in the unlikely event of damage to the nuclear fuel."

Even after Fukushima, it appears Entergy's public relations playbook has not changed: dispute the premise that a severe nuclear accident leading to a hydrogen explosion is even possible, while also offering up fuzzy assurances that Indian Point has all the "back-up equipment" needed to "protect the plant" against such an impossible event. Both assertions by the Entergy spokesman are incorrect. Severe nuclear accidents leading to hydrogen explosions are indeed possible, as the Fukushima and Three Mile Island nuclear accidents have demonstrated, and Indian Point, in reality, is *not* prepared to cope with the rate and amount of hydrogen produced in a severe accident.

Mr. Nappi's description of "equipment inside containment that automatically turns hydrogen gas into harmless water…" is almost certainly referring to the hydrogen recombiners that the plant has in each of its containments. (Indian Point Unit 2's containment has two "passive" (*i.e.*, self-actuating or "autocatalytic") hydrogen recombiners, which do not require electricity, and Indian Point Unit 3's containment has two electrically-powered thermal hydrogen recombiners.) These safety devices spontaneously recombine hydrogen and oxygen molecules, yielding steam and heat, when the local hydrogen concentration in the air exceeds about 1 percent by volume.

Hydrogen recombiners are intended to maintain the hydrogen concentration in the containment below levels that can support a hydrogen explosion (i.e., at about 4 percent by volume and above). However, contrary to Entergy's assurance of safety, there are *only two* recombiners in each of Indian Point's containments, and they have a very limited capacity: each recombiner can only eliminate several grams of hydrogen per second,[11] while up to five kilograms of hydrogen per second could be produced at certain points during a severe accident.[12]

During a meltdown at Indian Point, the two hydrogen recombiners would clearly *not* be capable of eliminating all, or even a significant fraction, of the hydrogen produced within the time frame needed to prevent an explosion. In fact, the NRC has itself stated that hydrogen recombiners would be "ineffective at mitigating hydrogen releases from risk-significant beyond design-basis accidents"—i.e., partial or complete core melts.[13]

In countries that seek to minimize the hydrogen explosion risk from these types of accidents, "a fleet of typically 40 units are installed inside a light water reactor (LWR) containment."[14] So it appears that Indian Point has only 5 percent of what European nuclear regulators regard as a prudent complement of hydrogen recombiners.

In reality, the two hydrogen recombiners in each of Indian Point's containments are merely intended to cope with the much smaller rate and quantity of hydrogen produced in a design-basis accident, not a severe accident (meltdown). A design-basis accident is a postulated accident that a plant's safety systems are designed to withstand while ensuring the reactor reaches a safe shutdown condition. It is partly defined as an accident in which less than 1 percent of the active fuel cladding would chemically react with steam.[15] Entergy's own technical information for Indian Point Unit 2's license renewal application states:

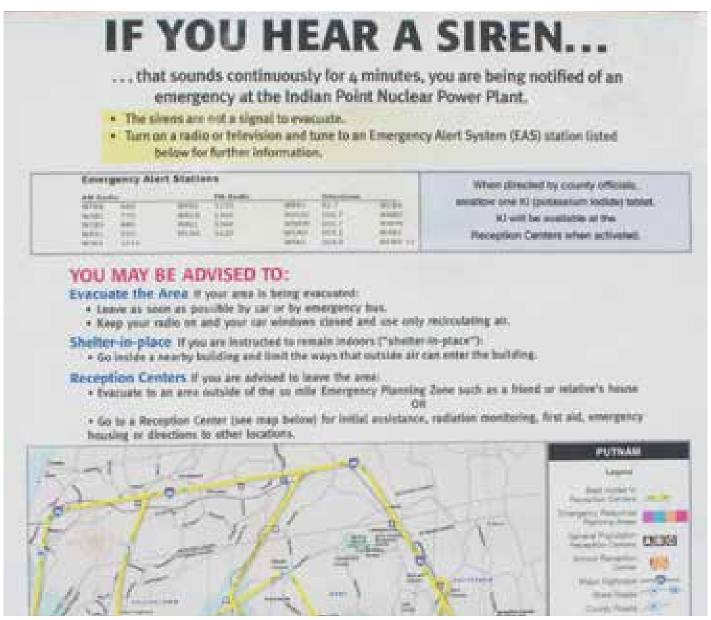
> The purpose of the hydrogen recombiners (HR system) is to reduce the hydrogen concentration in the containment volume following a design basis accident. The system includes two redundant passive autocatalytic recombiners that replaced earlier flame units.[16]

Ironically, however, according to the NRC, hydrogen recombiners are not even needed to mitigate hydrogen in design-basis accidents. In 2003, the agency eliminated the requirement for hydrogen recombiners, stating that the "Commission has found that hydrogen release [in a design-basis loss-of-coolant accident] is not risk-significant because the…hydrogen release does not contribute to the conditional probability of a large release [for] up to approximately 24 hours after the onset of core damage."[17]

In a severe accident (meltdown), more than 100 percent of the active fuel cladding could chemically react with steam,[18] because additional reactor core materials could also undergo rapid oxidation. Interestingly, an Indian Point safety study discusses a case in which interaction of the molten core with concrete would produce more than 6000 pounds (2721.5 kilograms) of hydrogen.[19] In light of these technical and regulatory conclusions, one wonders why a spokesman for Entergy would continue to cite a mere two recombiners in each Indian Point containment as an adequate defense against the severe accident scenario described in the Riverkeeper petition.

Indian Point's Token "Autocatalytic" Hydrogen Control Capability Could be Worse than None at All

Indian Point not only lacks a capability to control the levels of hydrogen that would be produced in a severe accident, but the token passive autocatalytic recombiner (PAR) capability it does have for Unit 2 could actually make a meltdown worse. This is because PARs can malfunction by producing unintended ignitions when exposed to elevated hydrogen concentrations.[20] Plant operators would be unable to switch off PARs—self-actuating safety devices—in a severe accident to prevent potential ignitions. Unintended ignitions are more likely to occur when the installed recombiner capacity is unable, as at Indian Point, to keep pace with the expected rate and total quantity of hydrogen production in a severe accident. In a meltdown, a hydrogen recombiner's ignition could cause a hydrogen detonation (an explosion with a combustion wave traveling faster than the speed of sound, relative to the unburned gas).[21]



CREDIT: EZRAGILDESGAME

Hydrogen detonations occurred in the Fukushima Dai-ichi accident. In April 2012, NRDC petitioned the NRC for a safety enforcement action at Indian Point that would either: 1) remove the unintended ignition hazard represented by the token PARs at Unit 2; or, 2) replace them with electrically-powered thermal recombiners that can be switched off in a severe accident if Entergy continues to assert this small capability as useful for hydrogen control in a design- basis accident.[22]

In a Meltdown, Plant Operators at Indian Point Cannot Implement Controlled Burns to Manage a Significant Buildup of Hydrogen inside its Containments

Unlike Entergy's spokesman, who cited a non-existent Indian Point recombiner capacity for mitigating hydrogen produced in a severe accident, a spokesman for the NRC responded to Riverkeeper's petition by highlighting a different, but equally illusory safety capability, at Indian Point. According to the November 15, 2012 *Poughkeepsie Journal* article, "NRC spokesman Neil Sheehan said plant operators could use controlled burns…to manage a significant buildup of hydrogen inside a [containment] dome." This is a reference to hydrogen igniters—safety devices designed to implement controlled burns in a meltdown scenario to help control a significant buildup of hydrogen inside the containments of boiling water reactor (BWRs) with Mark III containments and pressurized water reactors (PWRs) with ice condenser containments.

CREDIT: NRC.GOV

Unfortunately, for the NRC spokesman, Indian Point has two PWRs with large dry containments—*a design that does not have hydrogen igniters*. Hence, plant operators would not be able to implement controlled burns to manage a significant buildup of hydrogen inside of Indian Point's containments.

It is disturbing that a spokesman for the NRC would respond to a media inquiry about a nuclear safety concern at Indian Point by pointing to a safety capability that does not exist at the plant.

Managing a Significant Buildup of Hydrogen in a Severe Accident by Opening Existing Purge Lines in the Indian Point Containment Domes Would Result in Radiological Contamination of the Local Environment

According to the November 15, 2012 *Poughkeepsie Journal* article, "NRC spokesman Neil Sheehan said plant operators could…open purge lines to manage a significant buildup of hydrogen inside a [containment] dome." In a meltdown at Indian Point, attempting to manage a significant buildup of hydrogen by opening purge lines would result in a radiological release that would contaminate the local environment. Indian Point's containments do not have high-capacity venting-filtration systems that would help to retain the radioactive aerosols that would be released into a containment in a core meltdown.

Plant operators at Fukushima Dai-ichi purposely waited for local residents to evacuate before they opened the unfiltered vents in the primary containment of the coolant-starved Unit 1 BWR to relieve the high internal pressure.[23] Hopefully, in a meltdown at Indian Point plant operators would also wait for local residents to evacuate before opening containment vent lines in order to attempt purging a significant buildup of hydrogen contaminated with radioactive aerosols from the reactor core

In the event of a severe accident at Indian Point, attempting to purge a significant buildup of hydrogen from either of the containments would likely not be very beneficial, because the potential purge lines would not be capable of purging all or even a significant fraction of the hydrogen produced within the time frame needed to prevent an explosion. The potential purge lines would be different for each unit: Unit 2 has a post-accident containment vent system intended for use in a design-basis accident, while Unit 3's post-accident containment vent system was retired in 2003.

Entergy's technical information for Indian Point Unit 2's license renewal application states that "[t]he purpose of the post-accident containment vent…system was originally to provide a backup to the hydrogen recombiner as a method to reduce the hydrogen concentration in containment atmosphere post-[loss-of-coolant accident]"—in other words, after a design-basis accident.[24] Hence, Unit 2's post-accident containment vent system is not designed to cope with the rate and quantity of hydrogen production in a core meltdown scenario. The system is equipped with a filter for the "hydrogen-bearing gases from containment;"[25] however, the filter has a very low capacity: a flow rate of 200 standard cubic feet per minute (when the containment pressure is at 1.9 pounds per square inch gauge[26]), with a residence time in the charcoal filters of approximately 0.4 seconds.[27]

A flow rate of 200 standard cubic feet per minute is very low compared to the capacity of some European filtered-vent systems designed for de-pressurization in a meltdown, which have venting capacity of 3.5 to 12 kilograms per second for the steam-air-hydrogen mixture at pressures as high as 58 to 87 pounds per square inch.[28] Hence, in the meltdown scenario, Indian Point Unit 2's post-accident containment vent system would not be very useful because the containment pressure would significantly exceed the filter's flow and pressure capacity.

Moreover, in 2003, Entergy retired Indian Point Unit 3's post-accident containment vent system. Entergy said that containment depressurization and hydrogen control could be done by other means: 1) the containment purge system; 2) the containment pressure relief line; and 3) backflow to the steam ejector line.[29] However, if opened in the event of an accident, the containment purge system and the containment pressure relief line's valves are both designed to close within two seconds after receiving either a containment isolation signal or containment high radiation signal.[30] The NRC has advised that "[p]rovisions should be made to ensure that isolation valve closure will not be prevented by debris which could potentially become entrained in the escaping air and steam."[31] (The containment isolation valves are closed rapidly to minimize the amount of radiation that would be released.)

At Indian Point Unit 3, the isolation valves of the containment purge system, which has a 36-inch diameter line, are kept closed during reactor power operation. The system "is used for containment atmosphere cleanup, cool-down, and ventilation immediately prior to and during shut-down modes when containment personnel access is required;" and "the 10-inch containment pressure [relief] line is utilized to periodically relieve containment pressure buildup during reactor power operation." The containment pressure is required to be maintained at less than two pounds per square inch gauge during reactor power operation.[32] The containment pressure needs to be relieved for approximately two hours every two days.[33] (Indian Point Unit 2 operates the same way as Unit 3. It has a containment purge system and a containment pressure relief line with the same diameters as Unit 3's; yet, apparently, the containment pressure is relieved for approximately two to three hours per day.[34]) In sum, these pressure relief lines are designed to support routine reactor operation, not to function effectively in severe accident scenarios.

In the PWR meltdown scenario, any containment venting lines intended to purge hydrogen need to be heated to prevent steam condensation, which would help to reduce the risk of hydrogen combustion in the venting line.[35] (At different points, in a meltdown, there would be a large quantity of steam in the containment, which functions as an inerting dilution of the PWR containment atmosphere. If the steam were to condense in the venting line during venting, the inerting function of the steam would be lost and hydrogen in the venting line could combust.) In the 1990s, high-capacity containment venting-filtration systems were installed in all of the PWRs operating in France. Each French venting-filtration system is equipped with a metallic filter in the containment in order to retain a large portion of the radioactive aerosols that would be released in a meltdown; an additional sand filter is located outside of the containment to retain the remaining aerosols.[36] In the event of a meltdown, the French strategy for PWRs would be to implement filtered venting "to avoid any containment failure in the long term phase" of meltdown scenarios in which molten core concrete interaction would occur.[37] (Molten core concrete interaction would occur if the reactor pressure vessel were breached and the molten core flowed (or was ejected) onto the containment's concrete floor.) In other words, filtered venting in French PWRs would not be done to purge hydrogen in the early phase of an accident.

In summary: during a severe accident at Indian Point, opening potential purge lines would: 1) result in a radiological release that would contaminate the local environment, 2) not be capable of purging all or even a significant fraction of the hydrogen produced within the time frame needed to prevent an explosion, and 3) make the venting lines vulnerable to hydrogen combustion. Additionally, the potential purge lines—intended either for use during regular operation or design basis accidents—are not designed to withstand the high pressures expected to occur in the containment in a severe accident. Furthermore, there are no legally-binding regulations stipulating procedures for purging hydrogen from PWR large dry containments, and "strategies" for purging hydrogen in a PWR severe accident are ill-defined.

Conclusion

The two PWRs at Entergy's Indian Point Energy Center remain poorly equipped to minimize the risks of explosive hydrogen that would be produced in a severe nuclear accident involving one or both of these units. In light of this nuclear safety deficiency, Riverkeeper has petitioned the NRC seeking immediate enforcement action to shut down these units. If past is prologue, it seems likely the NRC will respond that the safety enforcement issue highlighted in the petition is not unique to Indian Point, and therefore constitutes a "generic issue" that must be pursued in a separate "rulemaking" proceeding that may take many years to reach fruition, or indeed may never be taken up by the Commission.

However, there is an alternative path to force consideration of this important safety issue. Both Indian Point units are currently involved in a hotly contested relicensing proceeding, in which both the State of New York and various citizen intervenors are opposing a 20-year license extension, on the grounds that continued operation of these 40 year old and technologically obsolescent units presents an unacceptable hazard to the 17.6 million people who live within a 50 mile radius of the plant. NRDC shares this fundamental risk perspective on Indian Point, and opposes continued operation of the reactors beyond their current license terms. Nonetheless, if these units are not slated for retirement when their current operating licenses expire, in September 2013 (Unit 2) and December 2015 (Unit 3), then major new capital investments for environmental protection will be required, not only to reduce coolant-intake fish kills and harmful thermal discharges to the Hudson River, but also to upgrade the plant's defenses against severe accidents.

Responsible regulatory authorities have the duty to ensure that all these necessary new investments are made part of Entergy's calculus whether it makes economic sense to continue operating Indian Point for another 20 years. Judging by their initial fumbled response to the Riverkeeper petition, Entergy continues to count on a pliable federal regulator to discount the true economic cost risk of a severe accident at Indian Point, while the NRC appears reluctant to step-up and perform its essential regulatory function, which is vital not only to preserving public health and safety, but also to a rational future allocation of resources for energy investment in New York State. Concerned citizens must continue to demand that both these organizations perform in a more responsive and responsible manner when the safety and economic well-being of the greater New York City area is at issue.

Endnotes

1 The petition was prepared by Mark Leyse, and is available here: http://www.riverkeeper.org/wp-content/uploads/2012/11/Petition-for-IP-Enforcement_Riverkeeper-FINAL-2.206_11-14-2012.pdf

2 Indian Point has two Pressurized Water Reactors with large dry containments, large cylinders with domes, comprised of reinforced concrete with a steel liner, a different design than Fukushima Dai-ichi's containments.

3 10 C.F.R. § 50.44 Combustible gas control for nuclear power reactors (http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0044.html).

4 The NRC task force report states: "PWR facilities with large dry containments do not control hydrogen buildup inside the containment structure because the containment volume is sufficient to keep the pressure spike of potential hydrogen deflagrations within the design pressure of the structure." See Charles Miller, et al., NRC, "Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident," SECY-11-0093, July 12, 2011, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML111861807, p. 42 (http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf).

5 According to the NRC's calculations, the pressure resulting from an adiabatic and complete hydrogen burn involving up to a 100 percent core metal-water reaction could be 114 psig for Three Mile Island Unit 1, 129 psig for Oconee Units 1, 2, and 3, and 135 psig for Turkey Point Units 3 and 4, which are all pressurized water reactors with large dry containments. See NRC letters regarding exemptions from hydrogen control requirements for Three Mile Island, Oconee, and Turkey Point (all written before 10 C.F.R. § 50.44 was revised in 2003 to no longer require hydrogen control for pressurized water reactors with large dry containments); available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Numbers: ML020100578, ML011710267, and ML013390647, respectively (http://pbadupws.nrc.gov/docs/ML0201/ML020100578.pdf), (http://pbadupws.nrc.gov/docs/ML0117/ML011710267.pdf), and (http://pbadupws.nrc.gov/docs/ML0133/ML013390647.pdf).

6 The design pressure of Indian Point Units 2 and 3's containments is 47 psig.

7 International Atomic Energy Agency, "Mitigation of Hydrogen Hazards in Severe Accidents in Nuclear Power Plants," IAEA-TECDOC-1661, July 2011, p. 10.

8 The potential consequences of a severe nuclear accident at Indian Point are described in an October 2011 NRDC Fact Sheet, "Nuclear Accident at Indian Point: Consequences and Costs," http://www.nrdc.org/nuclear/indianpoint/files/NRDC-1336_Indian_Point_FSr8medium.pdf

9 Natural Resources Defense Council, "Nuclear Accident at Indian Point: Consequences and Costs," October 2011, p. 1 (http://www.nrdc.org/nuclear/indianpoint/files/NRDC-1336_Indian_Point_FSr8medium.pdf).

10 Michael Risnit, Poughkeepsie Journal, "Riverkeeper Petitions NRC to Shut Indian Point: Environmental Group Says Accident Could Cause Explosion," November 15, 2012.

11 OECD Nuclear Energy Agency, "State-of-the-Art Report on Flame Acceleration and Deflagration-to-Detonation Transition in Nuclear Safety," NEA/CSNI/R (2000) 7 August 2000, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML031340619, p. 1.6.

12 E. Bachellerie, *et al.*, "Generic Approach for Designing and Implementing a Passive Autocatalytic Recombiner PAR-System in Nuclear Power Plant Containments," Nuclear Engineering and Design, 221, 2003, p. 158.

13 NRC, Federal Register Notice, Regarding Eliminating the Hydrogen Recombiner Requirement, Vol. 68, No. 186, September 25, 2003, p. 55419, emphasis added.

14 Ernst-Arndt Reinecke and Gerhard Poss, "Operational behaviour of passive auto-catalytic hydrogen recombiners," *Nuclear Engineering International*, 03 September 2012**.**

15 The NRC's regulation, 10 C.F.R. § 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors" states: "*Maximum hydrogen generation*. The calculated total amount of hydrogen generated from the chemical reaction of the [fuel] cladding with water or steam shall not exceed 0.01 times [one percent of] the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react."

16 Indian Point Energy Center, License Renewal Application, Technical Information, 2.0, "Scoping and Screening Methodology for Identifying Structures and Components Subject to Aging Management Review and Implementation Results," p. 2.3-61.

17 NRC, Federal Register Notice, Regarding Eliminating the Hydrogen Recombiner Requirement, Vol. 68, No. 186, September 25, 2003, p. 55419.

18 NRC, "Status Report on Study of Risk-Informed Changes to the Technical Requirements of 10 C.F.R. Part 50 (Option 3) and Recommendations on Risk-Informed Changes to 10 C.F.R. 50.44 (Combustible Gas Control)," SECY-00-0198, Attachment II, p. 6-6.

19 Power Authority of the State of New York, Consolidated Edison Company of New York, "Indian Point Probabilistic Safety Study," Vol. 8, 1982, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML102520201, p. 4.3-10.

20 "From the systematic investigation of the different PAR designs, it can be concluded that the ignition limits of all designs lie within around 5.5-7.5 vol.% hydrogen for dry air conditions, for higher steam concentrations around 8-9 vol.% hydrogen, reflecting the effect of steam inertisation on combustion processes," Reinecke and Poss, op. cit. See also, OECD/NEA THAI Project: "Hydrogen and Fission Product Issues Relevant for Containment Safety Assessment under Severe Accident Conditions, Final Report," NEA/CSNI/R(2010)3, 2010

21 "Hydrogen Removal from LWR Containments by Catalytic-Coated Thermal Insulation Elements (THINCAT)" states that "[i]n a situation when the hydrogen concentration rises, a delayed ignition [such as could be caused by a passive autocatalytic recombiner] enhances the risk because it may start a detonation." See K. Fischer, *et al.*, "Hydrogen Removal from LWR Containments by Catalytic-Coated Thermal Insulation Elements (THINCAT)," Nuclear Engineering and Design, 221, 2003, p. 146.

22 A summary of the NRC Petition Review Board's recent consideration of this safety issue can be found here: http://pbadupws.nrc.gov/docs/ML1228/ML12285A172.pdf

23 Institute of Nuclear Power Operations, "Special Report on the Nuclear Accident at the Fukushima Dai-ichi Nuclear Power Station," INPO 11-005, November 2011, pp. 11, 16-19.

24 Indian Point Energy Center, License Renewal Application, Technical Information, 2.0, "Scoping and Screening Methodology for Identifying Structures and Components Subject to Aging Management Review and Implementation Results," p. 2.3-159.

25 Ibid.

26 The value of a given pressure, relative to the atmospheric pressure at sea level (14.7 pounds per square inch), is expressed as pounds per square inch gauge.

27 Entergy, "Indian Point Unit 3: 10 C.F.R. 50.12 Exemption Request for Post accident Containment Ventilation System," October 3, 2002, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML022840451, Attachment 1, p. 2.

28 Bernd A. Eckardt, *et al.*, "Containment Hydrogen Control and Filtered Venting Design and Implementation," September 2001, p. 11.

29 NRC, Federal Register Notice, Regarding Indian Point Unit 3 Exemption for Post accident Containment Ventilation System, Vol. 68, No. 68, April 9, 2003, pp. 17412-17413.

30 Power Authority of the State of New York, "Indian Point Unit 3 Containment Purging During Normal Plant Operation," March 2, 1979, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML093420382, p. 2, Attachment 1, p. 1-3.

31 NRC, Standard Review Plan, 6.2.4, "Containment Isolation System,"NUREG-0800, April 1996, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: MLo52070461, p. 6.2.4-23.

32 Power Authority of the State of New York, "Indian Point Unit 3 Containment Purging During Normal Plant Operation," March 2, 1979, available at: http://pbadupws.nrc.gov/docs/ML0934/ML093420982.pdf, NRC Library, ADAMS Documents, Accession Number: ML093420982, pp. 1, Attachment 2, p. 1.

33 Ibid, p. 3.

34 Consolidated Edison Company of New York, Letter regarding Indian Point Unit 2, July 9, 1979, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML100980099, Attachment A., p. 1.

35 E. Raimond, *et al.*, "Continued Efforts to Improve the Robustness of the French Gen II PWRs with Respect to the Risks of Severe Accidents: Safety Assessment and Research Activities," Eurosafe, 2011, p. 7.

36 Ibid.

37 Ibid.

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